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Technical Progress Report (End Project)

Robust Localization, Classification, and Temporal Evolution Tracking in Auroral Data

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1 Introduction

This report is a summary of the progress for the effort on the AISR award NNG-05-GA88G. The project officially began on October 15, 2004 and ended on October 14, 2006, after a no-cost extension was granted. This report mostly re-states what was filed in the first year report; only a small amount of additional achievement followed from that point.

1.1 Problem Background

The NASA Polar mission's UVI sensor produces nearly 2,350 images per day. The sensor began operation in 1996 and produced over 8 million images. The huge number of images presents excellent opportunities for study of auroral phenomena but also presents challenges in finding the images of most interest for a particular investigation. To aid in the task of finding images of interest, Co-I Germany developed the On-line Search Tool, an interface to the database of UVI images. The tool allows retrieval of images based on time of collection and some simple auroral features. Various methods were developed previously and incorporated into the tool to allow mining of images and image meta data for the supported search keys. However, the tool's capabilities were limited by the challenging nature of the images, including high levels of noise, low contrast, and stars in some images. In addition, presence of day glow in many images can confuse the methods used by the tool's image miner.

1.2 Project Components

The project we report on here has three components, all related to development of algorithms that will allow more reliable automated detection of auroral arcs in NASA Polar UVI images. The project's ultimate goal was to allow the existing On-line Search Tool, which was developed under support of the AISR program, to exhibit enhanced image retrieval capabilities. The three components being tackled are aimed at supporting that larger goal. The three components are described next.

1.2.1 Improved Component Isolation

The first component involved improving the performance of an existing k-means-based semi-automated method for isolating auroral arc features (e.g., pieces/components of the auroral arc) from background in NASA Polar UVI images.

1.2.2 Forming a Coherent Arc

The second component involved developing a method (or methods) that automatically allow a coherent auroral arc to be localized in a UVI image, such as by joining small components of the arc into a unified whole without also joining non-arc components. The primary means to be investigated was shape-based processing via use of the Hough transform. Such mechanisms will tend to produce extracted forms that are exactly or nearly exactly elliptic in shape.

1.2.3 Refinement of Arc Description

The third component involved exploration of so-called active contour-based approaches in conjunction with the shape-based processing steps developed in the second component of the project. Efforts on the third component were to be quite modest for this project.

2 Brief Progress Summary

In this section, the progress on the project is briefly summarized. Many low-level details have been omitted; our aim is to provide a fairly high-level summary of progress. Focus is on the first and second components of the project. The third component is currently being tackled in a follow-on project.

2.1 K-means-based Methods

The SPSU sub-team, led by Co-I Hung, conducted experiments to help establish the qualitative performance of the k-means-based auroral arc segmentation scheme that they had developed previously. They also worked on means to improve the k-means approach.

One outcome is related to a study of the competing ways to localize the auroral arc. Since no comparative study of the performance of the k-means method for auroral oval segmentation versus the other existing methods ([4], [6], [7]) had ever been compared, we gathered results for a comparison study. We found that the k-means-based approach had comparable performance versus other existing approaches under some conditions. None of the prior approaches were really suitable for use in an automated system, though. (The work we describe related to the second component of our project is aimed at addressing that problem.)

2.2 Progress in Forming a Coherent Arc

The major effort was the development of an approach for automatically locating the complete auroral arc in UVI imagery. The approach is shape-based.

First, we established that the shape of the oval in UVI images should be elliptic. This finding is based on prior work in the field (e.g., [5, 8]). That work determined that in 3D space, the auroral oval is a circle, or at least is well-approximated by a circle. Since UVI's image is actually a projection of the auroral oval from real space onto the image plane, that projection can be proven to be elliptic in shape (since the projection of any circle onto another plane is elliptic [9]). The projection geometry is shown in Figure 1.

2.2.1 Aurora Oval Shape Characteristic

Experiments were performed in the project to empirically confirm the theoretical results. The experiment involves manually locating the auroral arc's outer boundary in 50 UVI images and then fitting a

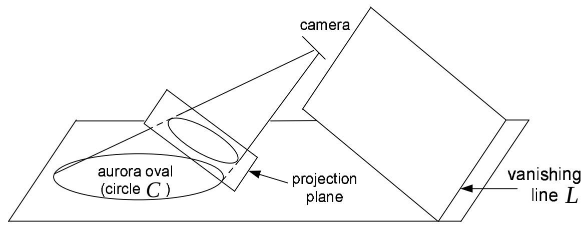


Figure 1. Illustration for projection of aurora oval onto UVI image

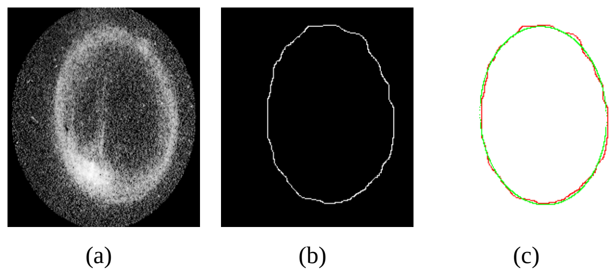


Figure 2. (a) Original image (b) Manually traced outer boundary (c) Fitted quadratic overlaid on outer boundary

general quadratic to those points using least squares. The general quadratic that was fitted is shown in Equation 1:

$$Ax^2 + By^2 + Cxy + Dx + Ey + F = 0\ . \tag{1}$$

The quadratic's type can be determined by shape invariants, $\triangle$, J, and I [11]:

$$\triangle = \begin{vmatrix} A & C/2 & D/2 \\ C/2 & B & E/2 \\ D/2 & E/2 & F \end{vmatrix}, J = \begin{vmatrix} A & C/2 \\ C/2 & B \end{vmatrix}, I = A + B.$$

Specifically, if $\triangle \neq 0, J > 0$, and $\frac{\triangle}{I} < 0$, the quadratic is an ellipse [11].

Figure 2 shows an example of one of our experiments. In part (c), the manually traced boundary is shown in red and the fitted boundary is overlaid in green.

2.2.2 Developed Methodology

Thus, the auroral oval should be expected to be oval in UVI images. The method we have developed in the project exploits this shape. The method's basic processing scheme is shown in Figure 3.

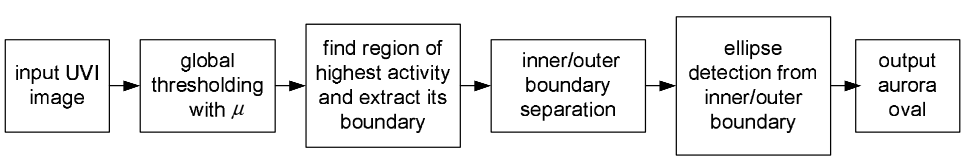


Figure 3. Shape-based aurora oval segmentation algorithm

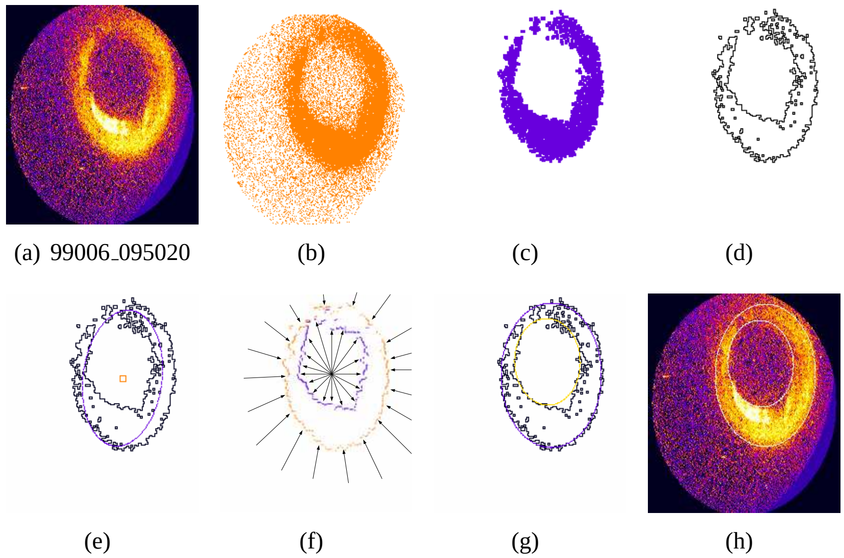


Figure 4. (a) Original image (b) Global thresholded result using μ (c) Dense part of (b) (d) Edge of dense part (e) Fitted ellipse to edge of dense part and its center (f) Radial based inner/outer boundary separation (g) Fitted ellipses to inner/outer boundary (h) Fitted ellipses overlaid on original image

We discuss only the ellipse detection part of the processing here. That processing is based on the Randomized Hough Transform (RHT) [10]. The RHT involves randomly selecting a few points in the image and using them to determine one likely set of parameters that describes the shape. RHT, like standard Hough, is a binning process that sets up a set of bins for each parameter. Each randomly selected set of points increments one of the bins. At the end of the process, the bin with the most votes is taken as the most likely parameterization of an ellipse.

An illustration of the processing steps for one image is shown in Figure 4.

2.2.3 Results

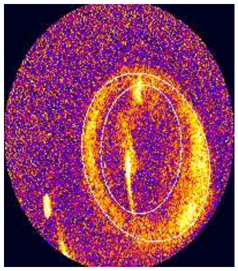
Some results of our method's application are shown in Figure 5

We have found the method we developed to be robust, even in the presence of various forms of image noise. In the future, we may be able to use the shape information determined from the localization process as features to support image mining based on shape.

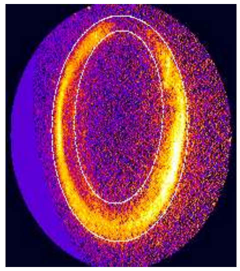
One outcome of our RHT-based work is that we have discovered that the methodology we use to find ellipses can be generalized to ellipsoid detection [1]. That form of result for RHT was not previously known in the literature.

2.3 Incorporation into Tool

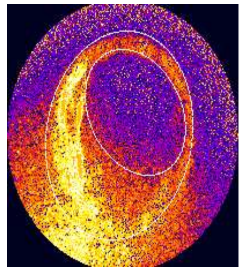
Efforts began to incorporate the method into the on-line search tool, but those efforts could not be completed within the limited time for this project. A follow-on project refined the method further and proceeded with incorporating the method into the on-line search tool.



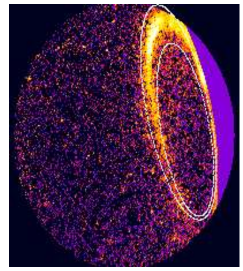
(a) 97011_022635



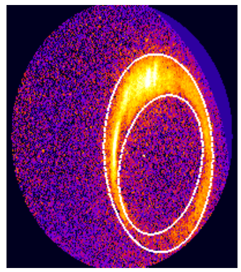
(b) 97011_032301



(c) 97212_052239



(d) 99006_031027



(e) 99006_075007

Figure 5. Some segmentation results

2.4 Publications

Results from this project also provided the basis for three publications ([1, 2, 3]). It should be noted that two of these publications ([1, 3]) also include some material developed outside the scope of this project, however.

3 Contributions to Education

We also would like to note some educational outcomes arising out of the project. A Ph.D. student in Computer Science at the UAH was supported by the project. As of this date, he is on track to finish the degree shortly. His primary activities on the project were realizing the Hough-based methods guiding auroral oval localization. He was the first author of a poster describing progress on the work that was presented at the Fall 05 AGU [2] and of two other computer science conference papers [1, 3]. Mr. Cao's capabilities dramatically improved as a result of his work on the project.

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